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ABSTRACT: Fabric functional finish and formulation of pesticides are factors that contribute to pesticide wicking, wetting, and penetration. Fluorocarbon soil-repellent finishes inhibit contamination of the fabric and of sentinel pads. An undergarment layer offers better protection than does a single layer. Spun-bonded olefin offers protection of the same magnitude as soil-repellent finishes. Methyl parathion residues after laundering were similar for the unfinished fabric, the durable-press finished fabric, and the soil-repellent finished fabric, but the initial contamination of the soil-repellent finished fabric was only 20% of that of the other two fabrics.

KEY WORDS: functional finish, soil-repellent finish, durable-press finish, pesticide soiling, wicking, wetting, pesticide penetration, pesticide residues, laundering, cotton/polyester blends, protective clothing

Chemical-resistant apparel is available to pesticide applicators; however, its use is often forfeited because of factors that include thermal properties, comfort, availability, cost, and lack of appreciation for the benefits. Common fabrics used for work clothing—cotton, polyester, and a blend of both—continue to be used for protective apparel. Pesticides spilled onto fabric may move (wick) through the fabric, wet underlying layers of fabric and skin, and be dermally absorbed. Investigations of fabric parameters (fiber content and functional finishes) and pesticide characteristics (concentration and formula-

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tion) will aid in understanding how protective clothing can minimize dermal exposure.

Accidental spilling of concentrated or diluted pesticides onto washable protective garments by urban commercial applicators, home gardeners, and agriculture workers has emerged as a concern. Current research has focused on the problems of penetration of pesticides impelled by air-blast sprayers [*1,2*], particulate matter attraction [*2*], and the difficulty of pesticide residue (spills) removal by laundering [*3-12*].

Generally, moisture can pass through textile layers such as those found in clothing in three ways: (1) by water vapor diffusion through the large pores and channels of the fabric, (2) by swelling of the fiber on one side and movement of this swelling water through the fabric, followed by final desorption to the environment on the other surface, and (3) by liquid transport through the capillary interstices within the yarn or fabric or along the fiber surface [*13*]. Wetting means that a liquid-solid interface replaces an original solid-gaseous phase boundary [*14*]. The fiber interstices of the textile represent a capillary system that takes up the liquid in the same manner as a bundle of parallel capillaries. The yarns act as wicks to carry moisture through the fabric.

Orlando et al [*1*] state that the penetration of pesticide is influenced by capillary forces. Fourt and Harris [*15*] theorize that the rate at which water vapor passed through a complex system such as layered fabric was determined not only by the fabric but also by the air layers between fabrics which contributed a large fraction of the total resistance of the fabrics to penetration. Little work has been done with pesticide penetration, but Finley et al [*9*] studied a two-layer assembly worn by cotton scouts in methyl parathion-sprayed fields. They found more than 50% of the contamination of the first layer of fabric passed through to the second layer of fabric. Factors such as fiber content, yarn and fabric geometry, and functional textile finish determine the response of a textile to soiling such as from liquid pesticides. The metrology of wicking and wetting, penetration to and through layers that represent garments or body surfaces, would enhance understanding of work clothing as protection. The role of a protective system such as spun-bonded olefin fabric merits investigation as an inhibitor to soiling by pesticides.

Fluorocarbon polymers alter the surface properties of fabrics so that oil as well as moisture has less tendency to wet the fabric surfaces, and wicking is reduced. Liquid soil is partially inhibited from wetting, wicking, or penetrating the fabric. However, soil removal can be a problem unless hydrophilic groups are incorporated in the finish [*16*].

Freed et al [*17*] and Orlando et al [*1*] conclude that textiles treated with fluorocarbon finishes afford significantly better protection to pesticide sprays than non-fluorocarbon-finished fabrics. However, Berch and Peper [*18*] warn that hydrophobic fluorocarbon soil-repellent (SR) finishes promote redeposition of soil in laundering. Berch et al [*19*] conclude that fluorocarbon finishes have a strong retentiveness for soil corresponding to a large tendency to become soiled in an aqueous system and that, generally, fabric systems that are readily soiled from a water medium also have a strong tendency to retain soil during laundering. Although SR fluorocarbon finishes may be more resistant to pesticide soiling from an SR-finished fabric than an unfinished fabric, no work to date has assessed whether pesticide soil is more difficult to remove from SR than from an unfinished fabric.

Application of resin finishes affects the water vapor absorption properties of cotton by producing a more rigid internal fiber structure that becomes less accessible to liquid water [*20*]. Durable-press (DP) resin finishes on cotton/polyester blends cause a greater increase in soiling of cotton than of polyester, because they increase the hydrophobic nature of cotton while decreasing that of polyester [*21*]. In addition, most additives in a DP finish exert an adverse influence on soil release [*22*]. Resin finishes that form intrafiber crosslinks reduce water absorbency because of less availability of cellulose hydroxyl for interaction with water, which reduces hydrophilicity [*23*].

The objectives of this research include the following: (1) to determine the extent of pesticide transport through and between fabrics and to assess whether methyl parathion (MeP) movement in fabric is dependent on fiber content, functional textile finish, pesticide formulation, or concentration; (2) to determine the retention of pesticide (MeP) in fabrics in areas of secondary exposure (that is, pesticide contamination by wicking, wetting, and penetration to an underlayer) and the effectiveness of laundering in removal of pesticide residues using procedures previously developed by the investigators of this research project; and (3) to make recommendations as to methods that can be used to reduce human exposure to pesticides through proper selection, treatment, and laundering of clothing used during application of pesticides.

Procedures

Fabrics

Three finishes on 50% cotton/50% polyester bottom-weight poplin fabrics were obtained from Testfabrics. These are described in Table 1. The finishes included (*a*) no finish (UN), (*b*) DP finish, and (*c*) UN with fluorocarbon SR finish. The SR finish was a consumer application with Scotchguard fabric protector, a product manufactured by the 3M Co.

The fabrics were initially stripped of warp sizing and manufacturer-applied fabric softeners by washing according to the American Association of Textile Chemists and Colorists (AATCC) Test Method for Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics (135-1978, Revised 1982). The outer 10% of the fabric was removed for preparation of test specimens as described in the ASTM Test for Breaking Load and Elongation of

TABLE 1—*Description of fabrics.*

Fabric	Designation[a]	Test Fabric Number	Fabric Count, yarns/10 cm	Weight, g/cm^2
50% Fortrel polyester/ 50% cotton poplin, bleached and mercerized	UN	7428	480 by 200	210
50% Fortrel polyester/ 50% cotton poplin, bleached with durable-press finish	DP	7428 WRL	480 by 200	210
50% Fortrel polyester/ 50% cotton poplin, bleached and mercerized with consumer-applied soil-repellent finish	SR	7428	480 by 200	210

[a]UN = unfinished; DP = durable press; SR = soil repellent.

Textile Fabrics [D 1682-64 (1975)] to ensure consistency of the warp yarns under evaluation.

The sentinel pads [*17*] were the Absorbent Cotton Company's Surpad (HRI-8035-90-8110) with dimensions of 28.4 by 25.3 cm (718.5 cm^2). The gauze pads were twelve ply folded to 7 by 7 cm (49 cm^2). These cotton pads were made from Type VII (7.9 yarns/cm by 4.7 yarns/cm) gauze. Spunbonded olefin was obtained from the Textiles Fiber Department of E. I. du Pont de Nemours and Co. The Tyvek was Style No. 1422A.

Contamination of the Fabric

Three formulations of MeP were investigated: emulsifiable concentrate (EC), wettable powder (WP), and encapsulated materials (ENC). Pesticide dilutions were prepared at 1.25% active ingredient (AI), a usual field strength concentration. Solutions were held in suspension during the contamination process by placing them on a magnetic stirrer. Two tenths of a millilitre were pipetted onto the fabric surface using a MicroLab P programmable micropipette. The fabrics were placed on a raised needle bed surface to minimize contact points during contamination. The micropipette unit was held in a padded ring stand, allowing a constant distance of 5 cm between the pipette tip and fabric surface.

Moisture-Related Fabric Properties

The contributions of fiber content and functional textile finish were examined for their effect on moisture-related fabric properties. Investigations of

MeP wicking, wetting, penetration through consecutive layers of fabric, and laundering of contaminated fabric were executed to determine the rate at which the MeP formulation moved through fabric. Distilled water served as the control liquid for the wicking and wetting operation. Three MeP formulations applied to three functional textile finishes were the variables under study. All the work was replicated three times. All the fabrics were conditioned in accordance with the ASTM Practice for Conditioning Textiles for Testing (D 1776-79) at 21 ± 1°C (70 ± 2°F) and a relative humidity of 65 ± 2% for a minimum of 48 h prior to testing.

Pesticide Wetting—The AATCC Test Method for Absorbency of Bleached Woven Cloth (79-1979) was used to determine the drop absorbency. This liquid absorption test was used to estimate the capillary-type penetration properties of fabrics. Fabric specimens, cut into 8-cm squares, were placed horizontally on a needled surface. A 0.2-mL drop of liquid (distilled water or pesticide solution) was pipetted onto the fabric surface, and the time required for the mirrorlike reflection properties of the drop to disappear was measured.

Pesticide Wicking—The wicking test involved migration of liquid through interfiber and interyarn capillaries of the fabric and measured the ability of a fabric to transport liquid [*20*]. The time required for liquid (distilled water or pesticide solution) to wick a distance of 3 cm on the specimen was measured using a protocol similar to that of Weirick [*24*]. Two stopwatches were started as the micropipetting began. One stopwatch was halted when the 3-cm spread was achieved (wicking), and the other stopwatch was stopped when the mirrorlike reflection disappeared (wetting). Because the SR finish repelled liquid from being absorbed into the fabric, the liquid bead on the surface was allowed to remain for 10 min, after which time the specimen corner was held vertically for 10 s to allow the pesticide bead to roll into a beaker.

Pesticide Penetration Through Fabric Layers—The amount of pesticide in solution that moved between layered fabrics was used to quantify pesticide penetration. Hypothetically, a liquid pesticide should move more readily through fabrics of high synthetic fiber content than through similar fabrics of more absorbent natural fibers.

Laundering of Contaminated Fabrics—Specimens of finished fabrics, 8 by 8 cm, were contaminated with EC and ENC MeP of 1.25% AI. Contamination procedures were as described previously.

The laundry variables included two water temperatures [60°C (140°F) wash and 49°C (120°F) rinse or a 49°C (120°F) wash and rinse] and two detergent formulations [heavy-duty liquid nonionic detergent (HDL) or AATCC Standard Detergent 124]. Both detergents had been shown to be effective in MeP removal at both water temperatures [*5*].

Extraction

The specimens were individually extracted in 100 mL of reagent-grade acetone on a mechanical shaker for 1.5 h at 120 rpm. The extract was decanted and replaced by an additional 100 mL of acetone for a second shaking. At the end of the 3-h shaking time, the fabric specimen was removed, and the two extracts were combined.

Gas Chromatographic Analysis

The extracts were either concentrated with nitrogen (N_2) stream evaporation or diluted with acetone to facilitate gas chromatographic analysis. A 1.0-mL aliquot of the adjusted extract was mixed with 9 mL of toluene and a known quantity of ethyl parathion (internal standard). One-microlitre aliquots were analyzed with a Varian 3700 gas chromatograph with CDS 111C data system using an electron capture detector. Separation was achieved on a 2 m by 2-mm glass column packed with 1.5% OV-17 and 1.95% OV-210 on 80/100 mesh Chromasorb WHP with a nitrogen flow of 30 mL/min. The injection, detector, and oven temperatures, respectively, were 220°C (428°F), 270°C (518°F), and 190°C (374°F).

Statistical Analysis

Statistical differences between the control and the layered specimen or laundered specimens were calculated using an analysis of variance (ANOVA) with an indication of significance at the $P \leq 0.05$ level. Means were then separated with a Duncan's multiple-range test [*25*].

Results and Discussion

Pesticide Wetting

The SR finish proved to be superior to the UN and DP finishes in minimizing wetting of the pesticide solution into the fabric. This occurrence is attributable to the SR finish converting the fabric to a hydrophobic system. Even after an allotted 10-min period, the solution remained in a bead formation atop the SR specimen surface; hence, the mirrorlike reflection was never altered because of the low-absorbency characteristics of the fabric. Because of these results, the SR finish data were omitted from statistical analyses. The DP and UN specimens were statistically different across all formulations ($F = 7.78$; df $= 1{,}14$; $P = 0.0139$), with the DP being more resistant to wetting (Table 2). This supports the findings of Chandler and Zeronian [*20*]. The unfinished fabrics had no modifications to affect absorption.

Among the three pesticide formulations included in this study, statistical differences were found only between the EC and ENC ($P = 0.0227$). The EC formulation most readily wetted the specimen because of the presence of higher levels of a surfactant or carrier solvent ingredient. The surface-reactive agent aided in breaking down surface tension of both the fabric and the liquid pesticide solution, thereby increasing their penetrability. WP formulations also contain a surfactant, but because of the presence of inert ingredients (such as clay, talc), pesticide wetting does not occur as rapidly. In the ENC formulation the pesticide is encapsulated in microscopic polymer beads; this bead structure inhibits immediate release of the pesticide into the fabric.

Pesticide Wicking

The SR finish inhibited pesticide absorption, penetration, and spreading so that the SR data were obviously superior to the UN and DP; hence, the data were omitted from statistical analysis (Table 2). Although no statistical difference was found between the UN and DP finishes, there was a trend for faster wicking on the DP fabric. Since DP finishes increase hydrophobicity, the mechanism for moisture transport of MeP is likely to be along and between fibers and yarns rather then by absorption into the internal structure of individual fibers. The measured wicking time for the ENC formulation was significantly slower than that for the EC ($P = 0.0017$) and WP ($P = 0.0477$) on both the UN and DP fabrics. This could also be attributable to (1) the microencapsulated composition of the formulation or (2) the lower percentage of surfactant in the ENC formulation.

TABLE 2—*Summary of wetting and wicking experiment results.*

Formulation and Fabric[a]	Wetting Time, s	Wicking Time, s
EC		
UN	5.5 ± 0.7	2.5 ± 0.1
DP	8.1 ± 1.0	2.2 ± 0.5
SR	+600.0	+600.0
WP		
UN	7.5 ± 0.4	2.9 ± 0.4
DP	9.4 ± 1.4	2.5 ± 0.3
SR	+600.0	+600.0
ENC		
UN	8.7 ± 0.6	3.1 ± 0.0
DP	12.9 ± 2.7	3.4 ± 0.1
SR	+600.0	+600.0

[a]EC = emulsifiable concentration; WP = wettable powder; ENC = encapsulated; UN = unfinished; DP = durable press; SR = soil repellent.

Pesticide Penetration

The penetration experiments examined whether differences attributable to fabric finish or pesticide formulation were observable in the amount of MeP that moved between layered fabrics. These experiments involved four phases: (1) the amount of pesticide taken up by the outer garment fabric, (2) penetration of pesticide through the outer garment fabric onto a dermal surface represented by a cellulose sentinel pad (fabric/pad), (3) penetration of pesticide through the outer garment fabric to an undergarment fabric and onto a sentinel pad surface (fabric/fabric/pad), and (4) pesticide penetration through a spun-bonded olefin to an outer garment fabric and onto a sentinel pad surface (spun-bonded olefin/fabric/pad).

Garment Fabric—To determine whether fabrics differentially sorbed pesticide, it was necessary to examine the fabric type and pesticide formulation. The sorption of MeP by the outer garment fabric then became the baseline for comparisons of pesticide retention or movement to other surfaces in the subsequent phases of the experiment. Although pesticide sorption ranged from 9.3 to 51.9 g/cm^2 (Table 3), the SR was consistently lower than the UN and DP, regardless of MeP formulation. However, the EC formulation was significantly higher than the WP or ENC formulation ($F = 5.381$; df = 2,32; $P \leq 0.05$) probably because of the surfactants in the EC and the particulate nature of the other two formulations. There were significant differences due to pesticide formulation, with less MeP sorbed when in an ENC formulation ($F = 6.586$; df = 2,130; $P \leq 0.05$). This observation was consistent across all the finishes.

TABLE 3—*Outer garment fabric sorption of methyl parathion.*[a]

Fabric Finish[b]	Formulation and Sorption, ng/cm^2[c]		
	EC	WP	ENC
UN	46.77$^{+/1}$	51.90$^{+/1}$	34.30$^{+/2}$
DP	43.88$^{+/1}$	48.42$^{+/1}$	34.14$^{+/2}$
SR	23.52 $^{0/1}$	16.34 $^{0/2}$	9.30 $^{0/2}$

[a]Means followed by same symbol within columns are not significantly different at $P = 0.05$, and means with the same number within rows are not significantly different at $P = 0.05$ (Duncan's multiple range test).
[b]UN = unfinished; DP = durable press; SR = soil repellent.
[c]EC = emulsifiable concentrate; WP = wettable powder; ENC = encapsulated.

Garment Fabric/Sentinel Pad—The outer garment fabric was placed over a cotton gauze sentinal pad which modeled a dermal surface [*17*]. Because the sentinel pad was a hydrophilic substrate, it was necessary to determine if this surface acted in a spongelike manner, drawing more chemical into the fabric system than normally would be found in the outer garment fabric. When the MeP in the outer garment fabric and sentinel pad were totaled (Tables 3 and 4) and compared with the outer garment fabric alone, no significant differences were found across fabric finishes or pesticide formulations ($F = 0.289$; df = 1,16). Therefore, the presence of the sentinel pad did not significantly alter the amount of MeP in the total fabric system. The amount of MeP found in the sentinel pads was small (0 to 3.54% of the pesticide in the total system), and there were no significant differences across fabric, finish, or formulation. Under these test conditions, the MeP moved through the outer garment fabric and contaminated the sentinel pad, emphasizing the need for additional dermal protection when the pesticide is a highly toxic or concentrated mixture, or both. Pesticide retained by the outer garment fabric/sentinel pad was less than the pesticide retained by the garment fabric alone except for the ENC formulation (Tables 3 and 4). A significant difference between the outer garment fabric alone and the fabric of the fabric/pad system was found only for the unfinished fabric when EC MeP had been used to contaminate the system ($F = 5.29$; df = 1,16; $P = 0.0034$). This was

TABLE 4—*Methyl parathion penetration through the outer garment fabric/sentinel pad system.*

	Formulation and Penetration, ng/cm^2 [b]		
Treatment [a]	EC	WP	ENC
UN			
Fabric	39.44	45.78	34.52
Pad	0.17	0.02	0.07
Total	39.61	45.80	34.59
% of total in pad	0.43	0.04	0.20
DP			
Fabric	40.01	37.17	38.51
Pad	1.42	0.05	0.14
Total	41.43	37.22	38.65
% of total in pad	3.54	0.13	0.36
SR			
Fabric	20.45	14.50	10.15
Pad	0.01	0.00	0.03
Total	20.46	14.50	10.18
% of total in pad	0.04	0.00	0.32

[a] UN = unfinished; DP = durable press; SR = soil repellent.
[b] EC = emulsifiable concentrate; WP = wettable powder; ENC = encapsulated.

because of the difficulty of extracting MeP from the two-fabric system, and it confirms the findings of Easley et al [*3*]. As was true for the outer garment fabric alone, the pesticide found in the outer garment fabric/sentinel pad system for SR fabrics was about half that recovered for the other two fabrics (UN, DP) ($F = 45.22$; df = 2,130; $P = 0.0001$). Thus, the SR fabric provided protection by limiting sorption of MeP into the fabric system.

Outer Garment Fabric/Undergarment Fabric/Dermal Pad—Among the three finishes under study, the SR-finished fabric afforded the greatest level of protection. In the multilayer trials, the pesticide found in the outer garment fabric layer with the SR finish was approximately 50% of the amount retained by the other two finishes. These findings are congruent with the residues of MeP recovered from the outer layer fabrics discussed earlier.

An additional layer of fabric that absorbs a liquid spill may assist in limiting a pesticide solution from contaminating a dermal surface. That is, the more moisture a fabric will sorb, the less liquid is available for dermal contamination; therefore, additional layers of fabric that take up pesticide may limit the contamination of a dermal surface.

The amount of pesticide that contaminated the second layer was small; however, there was evidence of greater contamination with the DP as the outer garment fabric. The finish had imparted a hydrophobic nature to the DP garment fabric so that the moisture take-up was reduced. The pesticide moved quickly through the DP outer garment fabric, resulting in greater contamination of the undergarment fabric. This was supported by the wicking/wetting data presented previously.

Similar to the findings for the fabric/pad, extremely small percentages of pesticide were found in the sentinel pad of the fabric/fabric/pad system (Table 5). Larger percentages of pesticide were found in the pad when the undergarment layer was a fishnet fabrication and the outer garment layer was a DP. Given the open construction of the fishnet fabric and the limited sorbability of a DP finish, pesticide movement could have been from outer garment layer to pad without involvement of the undergarment layer. Another possibility is that the undergarment layer retained less liquid because of the limited number of interstitial spaces causing the pesticide to move through the undergarment layer to the pad. It would be important to consider this type of undergarment fabric, because this is the surface next to the skin and contamination in this layer could be available for dermal sorption. Noteworthy is the small percentage of contamination of the garment fabric found in the undergarment layer regardless of the type of undergarment layer. These findings indicate the importance of wearing a second fabric layer.

The composition of that second layer is important. Generally, the sweatshirt or fleeced fabric as an undergarment retained more pesticide than did other undergarment fabrics evaluated in this study (Table 5). For the sweatshirt, the pesticide found in the undergarment layer ranged from 0.00 to 2.93% of the MeP in the outer garment layer. It appears that the sweatshirt

TABLE 5—*Methyl parathion adsorption through outer garment fabric/undergarment fabric/dermal, in nanograms per centimetre.*[a]

	Tee-Shirt			Fishnet			Sweatshirt		
Treatments	EC	WP	ENC	EC	WP	ENC	EC	WP	ENC
Treatment I									
Outer garment fabric (UN)	43.54	30.32	31.91	36.59	44.09	34.14	39.04	41.58	38.27
Undergarment fabric	0.04	0.01	0.04	0.40	0.01	0.04	0.99	0.02	0.08
Pad	0.09	0.00	0.03	0.03	0.01	0.04	0.03	0.00	0.04
Total	43.67	39.33	31.26	37.02	44.11	34.21	40.06	41.60	38.39
Pad % of total	0.21	0.00	0.10	0.08	0.02	0.12	0.07	0.00	0.10
Treatment II									
Outer garment fabric (DP)	43.97	37.91	36.97	38.53	43.88	33.16	34.81	58.66	36.31
Undergarment fabric	0.03	0.03	0.03	0.08	0.01	0.03	0.34	0.02	0.17
Pad	0.04	0.00	0.04	0.07	0.00	0.08	0.01	0.00	0.04
Total	44.04	37.94	37.04	38.68	43.89	33.27	35.26	58.68	36.52
Pad % of total	0.09	0.00	0.11	0.18	0.00	0.25	0.03	0.00	0.11
Treatment III									
Outer garment fabric (SR)	19.79	10.86	5.71	22.86	24.18	10.53	19.56	17.94	13.65
Undergarment fabric	0.00	0.01	0.03	0.29	0.00	0.38	0.57	0.00	0.05
Pad	0.00	0.04	0.03	0.00	0.00	0.04	0.00	0.00	0.04
Total	19.79	10.91	5.77	23.15	24.18	10.95	20.13	17.94	13.74
Pad % of total	0.00	0.36	0.52	0.00	0.00	0.32	0.00	0.00	0.03

[a]EC = emulsifiable concentrate; WP = wettable powder; ENC = encapsulated.

fabric enhanced movement of pesticide from the outer garment layer to the undergarment fabric. Contributing to the take-up of pesticide solution into the sweatshirt fabric was the acrylic/cotton fiber content, as both fibers are known to have good wicking tendencies and sorbency. Contamination of the tee-shirt layer was 0.00 to 0.52% that of the outer garment layer. For the fishnet, the contamination of the undergarment layer was 0.00 to 3.61% that of the outer garment layer. Because of the open network construction of the fishnet, the level of contamination varied greatly, contingent on whether the liquid soil contacted fabric or a space in the fabric.

The MeP in the total multilayer system was not significantly different from the amount of pesticide on the outer garment fabric alone. The pesticide in the outer garment fabric of the multilayer system was significantly different from that in the outer garment fabric alone in every instance except when the formulation was EC for UN over fishnet ($F = 8.39$; df = 1,16; $P = 0.102$) or sweatshirt ($F = 6.26$; df = 1,16; $P = 0.0221$) and DP over sweatshirt ($F = 16.11$; df = 1,15; $P = 0.0014$). Based on these data, tee-shirt fabric is recommended for the second layer.

Spun-bonded Olefin/Outer Garment Fabric/Sentinel Pad—Another mechanism for protecting the applicator is the use of disposable coveralls to be worn over work clothing when one is working with full-strength or highly toxic pesticides. The amount of pesticide moving to the garment fabric was greatly reduced (Table 6) when spun-bonded olefin was used as a protective system over outer garment fabrics. No significant differences were found in pesticide in the outer garment fabric, or second layer, because of the highly protective functions of the spun-bonded olefin, with its marked limiting of moisture penetration.

It is noteworthy that the amount of pesticide in the spun-bonded olefin/outer garment fabric/sentinel pad system was significantly less ($F = 19.97$; df $= 1{,}53$; $P = 0.0001$) than the amount of pesticide in the outer garment fabric/sentinel pad system in all instances except for the SR fabric and the ENC formulation. The amount of protection provided by the SR finish for a fabric was similar to the protection provided by the spun-bonded olefin protective system ($F = 0.799$; df $= 1{,}14$). The ENC formulation provided for limited sorption of pesticides in spun-bonded olefin/outer garment fabric/sentinel pad systems and outer garment fabric/sentinel pad systems.

Effectiveness of Laundering

Although many studies have examined factors affecting the completeness of pesticide residue removal in laundering, no work to date has examined the impact of functional textile finishes on the effectiveness of launderings. Contamination before laundering was significantly lower for the SR-finished fab-

TABLE 6—*Spun-bonded olefin/outer garment fabric/sentinel pad sorption (nanograms per centimetre of 1.25% methyl parathion).*

Treatments[a]	EC	WP	ENC
Treatment I			
spun bonded	28.73	12.64	21.64
garment fabric (UN)	0.03	0.08	0.27
pad	0.03	0.01	0.07
total	28.79	12.73	21.98
% of total in pad	0.10	0.08	0.32
Treatment II			
spun bonded	18.78	3.74	21.56
garment fabric (DP)	0.03	0.00	0.05
pad	0.03	0.00	0.01
total	18.84	3.47	21.62
% of total in pad	0.16	0.00	0.05
Treatment III			
spun bonded	18.78	13.71	20.86
garment fabric (SR)	0.00	0.00	0.04
pad	0.01	0.03	0.03
total	18.79	13.74	20.92
% of total in pad	0.05	0.22	0.14

[a]UN = unfinished; DP = durable press; SR = soil repellent.

ric than for the UN fabric or DP-finished fabric (Table 7). Contamination of UN and DP specimens was five times that of the SR specimen. The SR finish effectively limited pesticide retention.

No significant differences were found between detergent type or washing temperatures, although the removal was slightly greater at the higher temperature. Residues after laundering were markedly lower when the ENC formulation had been used to contaminate the fabric than when EC was the formulation. These findings are congruent with those of previous studies [*4-6*].

There were no significant differences in MeP residues after laundering attributable to the fabric finish of the specimen. Residues after laundering were 5.350, 5.787, and 5.163 ng/cm^2 for UN, DP, and SR, respectively. It is important to note that initial contamination of the SR specimen was 20% that of the UN and DP specimens. This confirms the findings of Bevan [*16*], Berch and Peper [*18*], and Berch et al [*19*].

It is apparent that pesticide soil removal is a greater problem for the SR-finished fabrics, although the residue level is in the same range as in the UN and DP fabrics. A certain irreducible amount of residue may remain after laundering, in such locations as the lumen of cotton. Further work is needed to confirm whether SR fluorocarbon finishes have a retentiveness for pesticides and to ascertain ways to optimize residue removal in laundering.

TABLE 7—*Methyl parathion residues in specimens after laundering.*

Treatment[a]	MeP, ng/cm^2	df	*F*	*P*
Initial contamination				
UN	82.737	2,18	4.875	0.0199
DP	80.411			
SR	16.598			
UN by DP		1,12	0.140	0.9169
UN by SR		1,12	8.931	0.0110
DP by SR		1,12	10.300	0.0075
Laundering temperature				
60°C	5.123	1,83	0.091	0.7604
49°C	5.743	1,83		
Detergent				
HDL	5.942	1,83	0.248	0.6256
Phosphate	4.924			
Formulation				
EC	12.363	1,83	59.129	0.0001
ENC	0.246			
Finish				
UN	5.350	2,82	0.032	0.9687
DP	5.787			
SR	5.163			

[a]UN = unfinished; DP = durable press; SR = soil repellent.

Conclusion

Encapsulated and emulsifiable concentrate formulations of methyl parathion move across and through fabrics, contingent on the functional finish applied to the fabric. Fluorocarbon SR finishes inhibit the movement of pesticide liquids through fabric, and contamination is approximately 18 to 20% that of unfinished or DP-finished fabrics. Based on these findings, recommendation is made for a soil-repellent finish for fabrics worn during mixing, handling, or application of pesticides.

Pesticide solutions move through fabrics to contaminate sentinel pads. DP finish is less desirable since MeP moves more readily through the fabric, thus allowing more pesticide to penetrate to the underlayer and to the sentinel pad. SR finish is highly desirable; spills move through the fabric more slowly, and less penetrates to undergarments or sentinel pads.

An undergarment layer offers better protection than does a single layer of clothing. The presence of a second layer does not contribute to movement to the sentinel pad. The contamination of the second layer is generally less than 1% that of the contamination of the outer garment layer; thus, the pesticide is not available for dermal absorption. A tee-shirt undergarment is recommended over other fabrics studied.

Spun-bonded olefin offers protection in the same magnitude as the SR finish. Based on these findings, recommendations are made for use of the disposable spun-bonded olefin garments or for SR finish applied to non-durable-press work clothing. Theoretically, the greatest protection may be realized in use of the disposable olefin garments worn during mixing, handling, and application of pesticides, in addition to SR finish on the usual work clothing.

Laundering variables of temperature and detergent type were not important in differences in pesticide residue after laundering. Differences in MeP residues after laundering were due to formulation of pesticide, with encapsulated formulations being more completely removed in laundering. Residues after laundering were similar across the unfinished fabric, the durable-press-finished fabric, and the soil-repellent-finished fabric. It is important to note that the initial contamination of the SR fabric had been only 20% that of the other two fabrics. The fluorocarbon polymer had rendered the fabric more hydrophobic, thus more soil resistant, but the finish promoted soil redeposition in laundering, and residue removal was a smaller percentage of contamination. Additional work is needed to assess the difficulty in dislodging pesticide residues from SR-finished fabrics through exploration of laundering factors that optimize pesticide soil removal.

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